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PEDIATRIC CARDIOLOGY

Early Results and Follow-Up of Balloon Angioplasty for Branch Pulmonary Artery Stenoses

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Two hundred eighteen balloon angioplasty procedures were performed in 135 patients with branch pulmonary artery stenoses from June 1984 to February 1989. Arteries were dilated in patients with tetralogy of Fallot (n = 49), tetralogy of Fallot/pulmonary atresia (n = 64), isolated peripheral pulmonary artery stenoses (n = 58) and "other" lesions (the majority had truncus arteriosus or single ventricle and surgically induced pulmonary artery stenoses (n = 47). Mean age at dilation was 6.6 ± 6.3 years (range 1 month to 38.5 years). The mean diameter of the lesion increased from 3.8 ± 1.7 to 5.5 ± 2.1 mm with dilation (p = 0.0001). The overall success rate was 58% (127 of 218 dilations), assessed by the following criteria: an increase ≥50% of predilation diameter, an increase >20% in flow to the affected lung or a decrease >20% in systolic right ventricular to aortic pressure ratio. Success did not correlate with patient age. Mean balloon to artery ratio was higher in successful (4.2) than in failed (3.0) angioplasty procedures (p = 0.0001).

There were four early deaths: two of the patients had pulmonary artery rupture with angioplasty performed <1 month after pulmonary artery surgery. An aneurysm occurred in 11 arteries and transient pulmonary edema in four patients. At angiography performed a mean of 10 months (range 1 to 54) after dilation, the mean diameter of 57 arteries was unchanged (5.5 versus 5.4 mm). However, 5 of 32 initially successfully dilated vessels had returned to predilation size as a result of restenosis. The most recent experience with angioplasty for branch pulmonary artery stenoses indicates a success rate of 60%, a mortality rate of 1% and a risk of aneurysm formation of 3%.

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Hypoplastic and stenotic branch pulmonary arteries may adversely affect the outcome of surgery for congenital heart disease (1–3). Surgery performed to directly relieve these pulmonary artery lesions has been difficult and often ineffective (4,5). Furthermore, stenoses of intraparenchymal pulmonary arteries can be surgically inaccessible. As an alternative to surgical angioplasty, balloon angioplasty has become established in several centers. Experimental studies (6) have indicated that balloon angioplasty succeeds by tearing part or all of the vascular intima and media, allowing vascular remodeling and healing at a larger diameter. These observations have been confirmed by clinical (7–9) and pathologic (10) studies.

Despite its increasing utilization, balloon dilation of pulmonary arteries is technically difficult and frequently unsuccessful; it has been associated with vascular rupture (8,9), unilateral pulmonary edema (11), thrombosis (12) and other complications. Because all previous reported series have been small, the incidence and predictors of success, the frequency of major and minor complications and the late follow-up findings have remained poorly defined. We have therefore reviewed our results of 155 cardiac catheterizations performed over 4.5 years to dilate 218 branch pulmonary arteries. Special attention was paid to mortality, incidence of aneurysm, unilateral pulmonary edema and restenosis, as well as newer advances in technique that have permitted dilation of more difficult lesions and more than one lesion per procedure.

Methods

Study patients. We reviewed the hemodynamic data, angiograms, radionuclide lung perfusion scans and medical records of 135 consecutive patients who underwent balloon

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Table 1. Summary of Diagnoses in 135 Patients

Diagnosis	Angioplasty Procedures (no.)
ToF	49
ToF/PA	64
Isolated PPS	58
Other	47
S/P truncus arteriosus repair	12
SV, S/P shunt	11
SV, S/P Fontan procedure	7
PA/IVS	7
TGA, S/P arterial switch repair	6
DORV	3
VSD, S/P PAB	1
Total	218

DORV = double outlet right ventricle; IVS = intact ventricular septum; PA = pulmonary atresia; PAB = pulmonary artery banding; PPS = peripheral pulmonary artery stenoses; S/P = status post; SV = single ventricle; TGA = transposition of the great arteries; ToF = tetralogy of Fallot; VSD = ventricular septal defect.

dilation angioplasty to relieve branch pulmonary artery stenoses at The Children's Hospital in Boston, from June 1984 to February 1989. Among the 135 patients, 77 (57%) were male, and the mean age at dilation was 6.6 ± 6.3 years (range 1 month to 38.5 years), with 7 dilations being performed in patients younger than 1 year and 6 in patients older than 20 years. A total of 218 stenotic arteries were dilated during 155 catheterizations.

Diagnoses. The arteries were grouped into four major categories by diagnosis (Table 1): tetralogy of Fallot (n = 49), tetralogy of Fallot with pulmonary atresia (n = 64), isolated peripheral pulmonary artery stenoses (n = 58), and "other" lesions (n = 47). Most of the patients in the group with "other" lesions had truncus arteriosus or single ventricle and had surgically induced branch pulmonary artery stenoses, often after aortopulmonary shunts or pulmonary artery banding.

Indications. The indications for balloon angioplasty were the following: 1) near systemic or higher right ventricular pressure, 2) hypertension in unaffected portions of the pulmonary vascular bed, presumably secondary to increased flow, 3) marked decrease in flow to the affected lung as assessed by radionuclide scan, or 4) symptoms.

Dilation technique. The technique of the angioplasty procedure has been described previously (13). After standard premedication, vascular access is established percutaneously, usually in a femoral vessel. A balloon-tipped catheter is advanced through a venous sheath and used to measure right-sided hemodynamics. A small pigtail catheter is inserted into a femoral artery and placed in the descending aorta to monitor blood pressure and blood gases during the procedure.

Angiograms are performed in each pulmonary artery or the affected vessel. The caliber of the stenotic segments is measured (with relation to known catheter dimensions) in optimally angled angiographic views. Whenever possible, the worse lesion is dilated first, because balloon occlusion causes the smallest decrease in flow and should be well tolerated. An end-hole catheter is positioned past the stenosis, and an appropriately sized (usually 0.035 or 0.038 in. [0.089 or 0.099 cm]) exchange wire is passed as far distally as possible in the lungs. Special care is taken to be certain that the wire is in the largest caliber distal vessel. In arteries that may be difficult to enter, the stiff end of the wire is frequently advanced into the distal vessel. After removal of both catheter and sheath, the angioplasty catheter is introduced. Balloon dilation catheters were manufactured by Medi-tech, Mansfield Scientific, ACS or USCI. Ideal balloons for pulmonary artery dilations have a short distal tip, a small deflated balloon profile and high inflation pressures. Rapid inflation cycles have not been considered important. The initial balloon size is chosen to be 3.5 to 4 times the diameter of the stenosed segment; relatively larger balloon ratios are used in younger patients and smaller balloon ratios in older children and adults. The balloon is inflated partially and positioned so that the waist of the stenosis is centered on the balloon. The balloon is then fully inflated until the waist disappears, gets visibly larger or the maximal "safe" inflation pressure is reached. If the initial result is unsatisfactory, a larger balloon may be used in subsequent dilations. Inflation time ranges from 10 to 60 s, depending on the response of the waist and the degree of interference with pulmonary blood flow and hence cardiac output.

After dilation, the angioplasty catheter is exchanged for a cutoff pigtail catheter. Using a Y adapter (USCI) at the end of the angiographic catheter, repeat pressure measurements and angiograms are performed. Leaving the wire in place allows for redilation if necessary or for prompt access to the vessel in case of complication. Care is taken not to cross previously dilated segments because of the risk of dissection at the site of an intimal tear. Postdilation manipulations are always made with either balloon-tipped catheters or very soft torque-controlled guide wires (Wholley wire, ACS).

In patients with multiple stenoses, more than one vessel may be dilated at the same catheterization. In this series, multiple vessels were dilated at the same catheterization in 47 patients: two vessels in 35 patients, three vessels in 8 patients and four or more vessels in the other 4 patients.

Dilations through shunts. Six patients underwent pulmonary artery angioplasty through a surgically created aortopulmonary shunt: right Blalock-Taussig in four and central shunt in two. The technique for dilation through a shunt is similar to that described for other dilations, although special care is taken to minimize shunt occlusion time and the risk of shunt damage during balloon inflation.

Lung perfusion. The proportion of pulmonary blood flow to each lung was frequently determined before and after dilation by injecting technetium-99 tagged to macroaggre-

gated albumin and detecting counts in each lung (14). The absolute change in pulmonary blood flow to one lung was calculated by multiplying the total pulmonary blood flow obtained at catheterization by the percent change in flow as assessed by radionuclide lung scan.

Criteria for success. A successful dilation was arbitrarily defined as 1) an increase ≥50% of predilation diameter, 2) an increase >20% in flow to the affect lung, or 3) a decrease >20% in the ratio of systolic right ventricular to aortic pressure.

Statistical analysis. Results are expressed as mean values ± SD. Statistical group comparison was performed using two-tailed *t* tests (paired or unpaired where appropriate) or analysis of variance (for multiple groups). Significance was defined as a p value <0.05.

Results

Success rate. The mean diameter of the stenotic segment in the 218 vessels increased from 3.8 ± 1.7 to 5.5 ± 2.1 mm with dilation (p = 0.0001). The average increase in diameter for all patients was 62% (range 0 to 500%). The diameter increased ≥50% in 110 vessels (Fig. 1 to 3), by 20% to 49% in 38 vessels and by <20% in the other 70 vessels. Despite an increase in diameter of <50%, 17 dilations were accompanied by a large increase in flow to the affected lung (>20%) or a decrease in systolic right ventricular to aortic pressure ratio >20%. Therefore, the overall success rate was 58% (127 of 218 dilations).

Determinants of success. Success rate did not differ among groups of patients with tetralogy of Fallot, tetralogy of Fallot with pulmonary atresia or isolated peripheral pulmonary artery stenoses (combined mean percent increase in diameter 51% ± 54%). However, in the group of patients labeled "other," the success rate was significantly higher (combined mean percent increase in diameter 101% ± 108%, p < 0.05).

In contrast to a previous smaller series (8), there was no correlation of success with patient age at the time of dilation (Fig. 4). In patients aged <3 years, 53% (39 of 73) of arteries were successfully dilated, whereas in those older, the success rate was 61% (88 of 145 arteries).

For all dilations, the mean balloon to artery ratio was 3.7 ± 1.6. There was a positive correlation of balloon to artery ratio and success: the mean balloon to artery ratio was 4.2 ± 1.9 in the successful and 3.0 ± 0.9 in the unsuccessful angioplasty procedures (p = 0.0001). Balloon to artery size ratio was only a partial determinant of success: of 91 dilations performed at a ratio >3.5, the success rate was 73%. The maximal balloon inflation pressure ranged from 3 to 10 atm (mean 5.4 ± 1.4). There was no significant difference in the maximal inflation pressure in the successful compared with the unsuccessful dilations (5.5 ± 1.4 versus 5.2 ± 1.4 atm, respectively, p = 0.3).

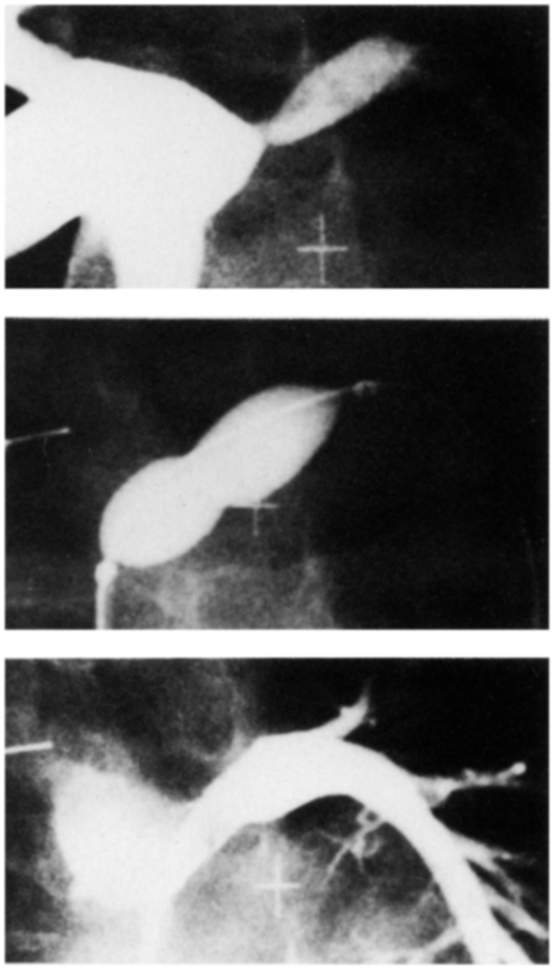

Figure 1. Successful balloon angioplasty of a proximal left pulmonary artery stenosis. **Top**, Predilation angiogram; **middle**, inflated balloon angiogram and **bottom**, postdilation angiogram.

Among the six patients who underwent dilation through an aortopulmonary shunt, three procedures were successful (Fig. 3). In one patient, after unsuccessful dilation with a small balloon, attempts to pass a larger balloon through the shunt were not fruitful. In the other five dilations, a catheter with the desired balloon size was used (mean balloon to artery ratio 4.2).

Changes in lung perfusion. Pre- and postdilation radionuclide perfusion scan data were available in 43 of the 88 patients who underwent a unilateral dilation. The average increase in flow to the ipsilateral lung for all patients was 70 ± 179% (p = 0.2). In 26 patients in whom the diameter increased >50%, flow increased by 90 ± 215%. However, 12 of these 26 patients had an increase of <20%, and by angiography they had severe disease with multiple peripheral stenoses. In contrast, in 17 patients in whom the diameter increased <50%, flow increased by 40 ± 99%. Among the latter, 11 had no change in flow, whereas 6 had an increase in flow of >20%.

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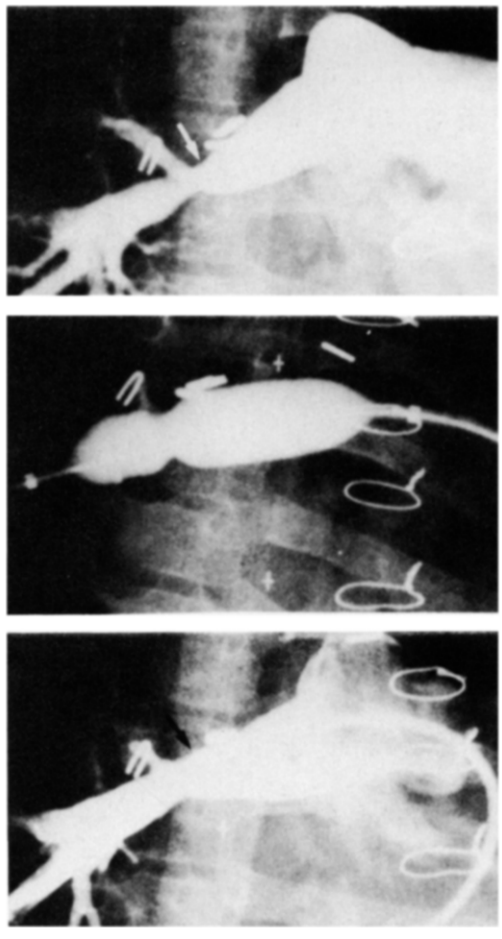


Figure 2. Successful balloon dilation of a right pulmonary artery stenosis. **Top,** Preangioplasty angiogram shows narrowing at the level of the right upper lobe pulmonary artery origin (**arrow**). **Middle,** The inflated balloon angiogram. **Bottom,** In the postdilation angiogram the diameter has increased and irregularity in the vessel wall (**black arrow**) suggests an intimal tear.

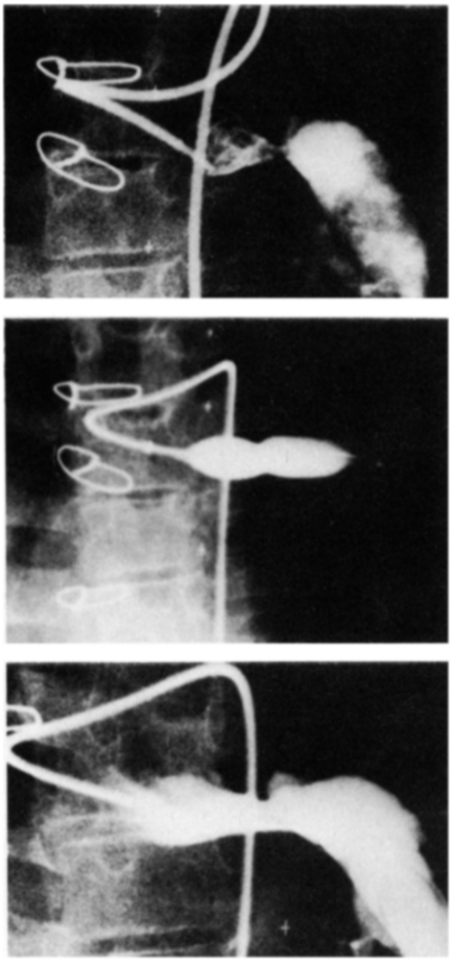
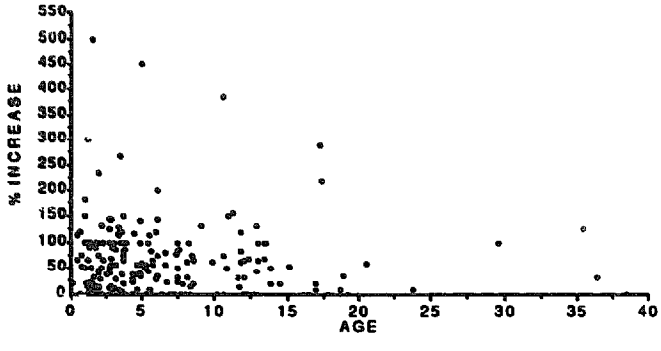


Figure 3. Successful balloon angioplasty of a left pulmonary artery stenosis through a central aortopulmonary shunt. **Top,** Predilation angiogram; **middle,** inflated balloon angiogram and **bottom,** postdilation angiogram.

Effect on right ventricular pressure. To determine the effect of balloon angioplasty on right ventricular pressures, pre- and postdilation systolic right ventricular pressures (expressed as a percent of systolic aortic pressure) were compared in 84 patients with an intact interventricular septum or a restrictive ventricular septal defect. The average systolic right ventricular pressure decreased from 84 ± 22% of systemic pressure before dilation to 72 ± 21% after dilation for all 84 patients ($p = 0.0001$). In 20 patients with isolated peripheral pulmonary artery stenoses, the average right ventricular pressure decreased from 96 ± 24% to 80 ± 21% of systemic pressure with angioplasty. In this latter group, 9 patients (45%) had a decrease in right ventricular pressure >20% of aortic pressure.

Complications. There were four early deaths. Two of them occurred among 12 patients who underwent dilation emergently because of low cardiac output after cardiac surgery. A 7 year old girl with tetralogy of Fallot underwent repair with a transannular right ventricular outflow patch and ventricular septal defect closure. The left pulmonary artery

Figure 4. Relation of patient age (years) to percent increase in pulmonary artery diameter with balloon angioplasty. Regression analysis: $y = -0.61x + 65.9$, $r = 0.053$, $p = 0.43$.



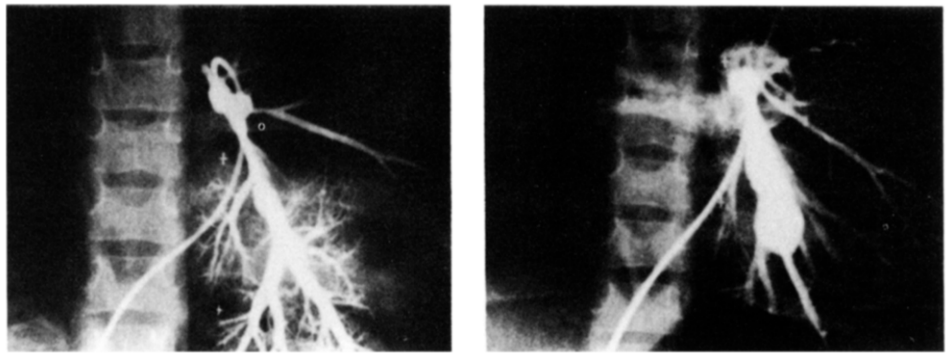


Figure 5. Development of an aneurysm after balloon angioplasty. Predilation (left) and postdilation (right) angiograms showing the formation of a saccular aneurysm in the left lower lobe pulmonary artery.

was dilated without fluoroscopy intraoperatively. She underwent catheterization 4 days later because of chest tube hemorrhage and low cardiac output. A large aneurysm was observed in the left pulmonary artery from the intraoperative angioplasty. Dilation of a stenosis in the right pulmonary artery was followed by vessel rupture, cardiac arrest and death. The second patient was a 3 year old boy with tricuspid atresia who underwent a modified Fontan procedure. Cardiac catheterization was performed 2 weeks later because of persistent pleural and pericardial effusions and signs of low cardiac output. Left pulmonary artery dilation resulted in vessel rupture and hypotension. Despite resuscitative efforts and surgical repair of the ruptured pulmonary artery, he died 2 days later.

The third patient, with truncus arteriosus and interrupted aortic arch, had undergone conduit placement from the ascending to the descending aorta and bilateral pulmonary artery banding at age 1 day. The right and left pulmonary bands were removed at age 2 and 4 years, respectively. Catheterization at age 5 years revealed a systolic right ventricular pressure of 145 mm Hg, moderate conduit obstruction and severe bilateral pulmonary artery stenoses. Angioplasty of the left pulmonary artery stenosis was accompanied by dramatic disappearance of the waist in the balloon and an increase in distal pulmonary artery pressure (mean 60 mm Hg). For unclear reasons, 20 min later the patient became hypotensive and bradycardic and could not be resuscitated. There was no evidence of adventitial rupture at postmortem examination.

The fourth patient was a 21 month old boy with Williams syndrome, bilateral pulmonary artery stenoses and suprasystemic right ventricular pressure (170 mm Hg). Passage of an uninflated angioplasty catheter into the main and left pulmonary arteries was followed by profound hypotension, bradycardia and death.

Aneurysms. Eleven angioplasty procedures (5.0%) were complicated by the development of an aneurysm. An aneurysm was defined as a saccular formation that tapered abruptly and measured at least twice the diameter of the adjacent pulmonary artery (Fig. 5 and 6). Obviously, because dilation succeeds by tearing the vessel wall, definitions of what constitutes an aneurysm are somewhat arbitrary. The patients who developed an aneurysm tended to be younger (3.5 ± 3.8 years) than those who did not (6.8 ± 6.3 years) ($p = 0.1$). The balloon to artery ratio (3.5 ± 1.1) and maximal inflation pressure (5.5 ± 1.5 atm) were not significantly higher in the patients who developed an aneurysm. In most cases, the distal portion of the balloon had been inflated in a very small vessel; that vessel became the site of aneurysm formation. One patient developed a large proximal right pulmonary artery aneurysm after dilation and died during corrective surgery when the left coronary artery was accidentally interrupted. Follow-up angiograms were available for six aneurysms. Of these, four were unchanged at a mean follow-up of 1.9 years, and two had decreased slightly in size after 1.2 and 4.3 years, respectively.

There were several other complications. In three patients, the vessel ruptured (as evidenced by contrast extravasation on angiography). Two of these patients did not require intervention; the third had rupture of the right pulmonary artery followed by acute widening of the mediastinum and hypotension, and the vascular tear was repaired surgically after volume resuscitation. Another four patients developed transient pulmonary edema after dilation. Angioplasty in another four patients was followed by total occlusion of a small adjacent pulmonary artery. One patient had transient hemoptysis, and another required surgical repair of a torn femoral vein after removal of a balloon that had ruptured circumferentially during inflation. Transient asymptomatic hypotension was not uncommon but was especially severe (and life-threatening) in children with combined right and left ventricular obstructions.

Follow-up and restenosis. Follow-up angiograms were available for 57 procedures. There was no significant difference in the mean diameter immediately after dilation (5.5 ± 2.1 mm) and at follow-up (5.4 ± 2.4 mm) 10 ± 11 months after the procedure. By diameter criteria, 32 of these 57 procedures were initially successful, and in this group the diameter was 5.6 ± 2.3 mm immediately after dilation and 5.8 ± 2.2 mm at follow-up 10 ± 12 months later. Among these 32 initially successfully dilated vessels, 5 had narrowed

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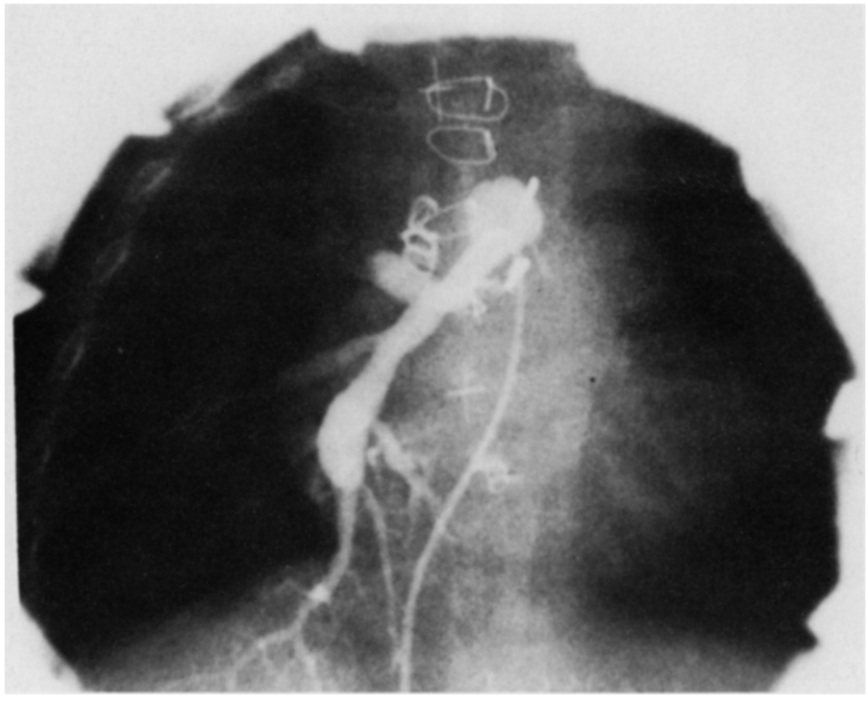

Figure 6. Example of postangioplasty vessel enlargement that we did not consider to be an aneurysm. Although there is a saccular formation in the right lower lobe pulmonary artery, it is only slightly larger than the adjacent proximal vessel.

to near predilation size at follow-up, indicating a restenosis rate of 16%.

Early versus more recent experience. The results and complication rates were compared for balloon angioplasty performed before 1986 (early experience) and that performed from 1986 to February 1989. Before 1986, 49% of angioplasties were judged to be successful. In contrast, from 1986 to early 1989, 60% of procedures were deemed to be successful. The mortality rate in the early period was 5% (2 of 39), and after 1986 it was approximately 1% (2 of 179). The incidence of aneurysm formation was 13% (5 of 39) before 1986 and 3% (6 of 179) from 1986 to early 1989.

Discussion

This review comprises the largest reported series to date evaluating the results of balloon angioplasty for branch pulmonary artery stenoses. The success rate of 58% is similar to that previously reported (8).

Diagnoses. There was no difference in success rate for patients with tetralogy of Fallot, tetralogy of Fallot with pulmonary atresia and isolated peripheral pulmonary artery stenosis (combined average 54%). In contrast, patients in the group with "other" conditions had a higher success rate (74%). Many patients in the latter group had pulmonary artery stenoses either at the site of previous pulmonary artery banding or in the area of insertion of an aortopulmonary shunt, suggesting that surgically induced fibrotic tissue at these stenotic sites is more amenable to balloon dilation than are native lesions. However, stenosis at the insertion site of an aortopulmonary shunt must be differentiated from tenting and distortion of a "normal" vessel as a result of tension exerted by the shunt (Fig. 7). The latter was observed in two patients with unsuccessful balloon angioplasty, one of whom underwent surgical division of the shunt with spontaneous enlargement to a nearly normal-sized right pulmonary artery.

One possible reason for the lower success rate in patients with tetralogy of Fallot (especially with pulmonary atresia) and isolated peripheral pulmonary artery stenosis is that these patients frequently have multiple areas of stenosis and are less likely to have an increase in flow (by lung scan) or a decrease in right ventricular pressure after dilation. In an attempt to improve the results of angioplasty in these patients, we have been dilating at least two arteries at the same catheterization, with no apparent increase in the rate of complications.

Age. A previous smaller report (8) suggested a higher success rate for branch pulmonary artery angioplasty in patients aged <2 years. In this series, there was no correlation between success and patient age at dilation. However, since most pulmonary artery growth occurs before the age of 2 years (15,16), we still recommend balloon dilation at a relatively young age. Newer, lower profile balloon catheters have made it possible to perform percutaneous procedures in patients as small as 7 to 8 kg in weight with very low risk of permanent femoral vein injury.

Unusual approaches. Our experience in six patients suggests that pulmonary artery angioplasty can be performed as successfully through an aortopulmonary shunt as through the right ventricular outflow tract. In addition, the percutaneous site for angioplasty does not necessarily have to be

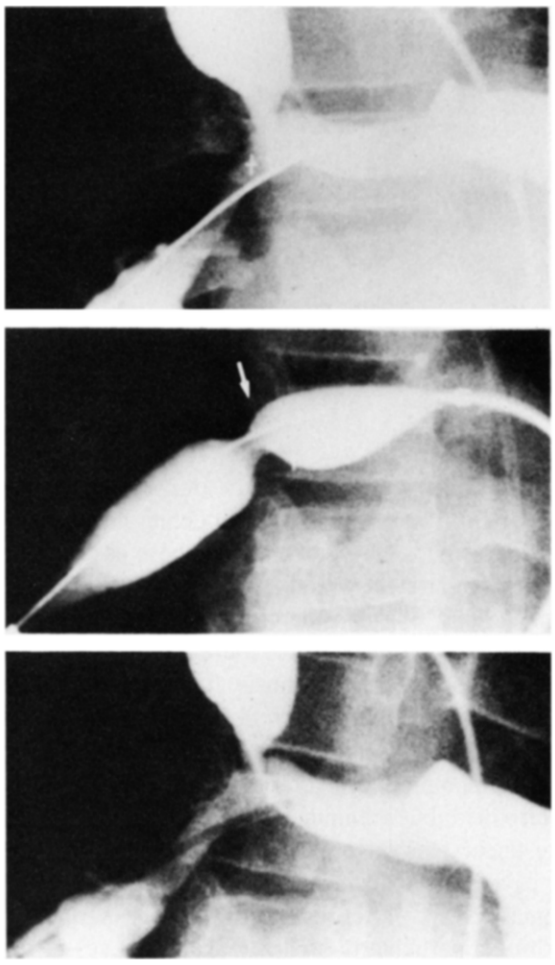

Figure 7. Example of right pulmonary artery distortion as a result of tension from a Blalock-Taussig shunt. **Top**, Predilation angiogram. **Middle**, Inflation of the balloon results in a discrete waist (**white arrow** depicts shunt insertion site). **Bottom**, There was no significant increase in vessel diameter on the postdilation angiogram. However, at the time of subsequent surgical division of the shunt, the narrowed segment enlarged spontaneously to a nearly normal-sized right pulmonary artery.

confined to femoral vessels. We have successfully dilated two of three stenoses (one at the site of a superior vena cava to right pulmonary artery anastomosis) (Fig. 8) through a subclavian vein.

Balloon size. Consistent with a previous report (8), a larger balloon to artery diameter ratio was associated with a higher success rate. Use of balloons >3.5 times the diameter of the stenosis was more successful than dilation with smaller balloons (73% versus 45%). However, the choice of balloon size may be limited by the diameter of the artery proximal and distal to the stenosis. We believe that inflation in a small distal vessel was responsible for most of the aneurysms that we encountered. Consequently, we currently dilate with an initial balloon larger than three times the diameter of the lesion, ensuring that the distal balloon is inflated in the largest distal pulmonary artery branch.

There was no difference in maximal balloon inflation pressure between successful and unsuccessful angioplasty procedures. Rather, success appeared to be associated more with disappearance of the stenosis waist on the balloon. In most angioplasty failures, the waist persisted, often despite high inflation pressures or balloon rupture.

Lung perfusion. The change in flow to the ipsilateral lung was not significantly different for arteries that increased >50% in diameter than for arteries that did not. One explanation is that despite an increase in diameter, flow may not increase (12 of 26 patients in this series) because of multiple areas of stenosis or hypoplasia. In addition, flow may increase significantly in arteries that have <50% increase in diameter, because flow is proportional to the fourth power of the radius. Also, single plane (or even biplane) angiography may fail to adequately profile the arterial dimension that has the largest increase in diameter. One drawback of analyzing right versus left lung flow is that it ignores regional changes in perfusion. When bilateral angioplasties are performed, despite no overall change in flow ratio between the right and left lungs, it is possible to obtain large regional (lobar) increases in flow, resulting in better matching of perfusion and ventilation. The overall benefit to the patient in such instances is difficult to assess unless individual pulmonary vein blood gases are obtained, arterial saturation changes significantly or regional pulmonary flow and ventilation are carefully analyzed.

Right ventricular pressure. An elevated right ventricular pressure has been shown to be associated with a higher incidence of arrhythmias (17), exercise intolerance (18,19) and right ventricular failure (20). Another variable used to evaluate success of angioplasty is a decrease in systolic right ventricular pressure. In this series, right ventricular pressure decreased significantly (from 84% to 72% of systemic pressure) in all 84 patients with complete data. In patients with isolated peripheral pulmonary artery stenoses, which have been previously considered particularly undilatable (8), nearly one half had a decrease in right ventricular pressure >20% of systemic pressure with angioplasty.

Complications. The two deaths occurring at angioplasty in the early postoperative periods suggests that patients treated early after surgery are a particularly high risk group. The two patients who died had pulmonary artery rupture, presumably in the region of a recent surgical suture line. Dilation in the early (<2 to 3 months) postoperative period should be entertained only when continued medical management appears to carry a very high risk and no other therapeutic options seem viable. At present, we start with a small balloon to artery ratio when dilating in the early postoperative period.

Aneurysms. Aneurysm formation was not associated with larger balloon to artery ratios or higher maximal inflation pressures. Aneurysms occurred mostly in small branches distal to the stenosis, suggesting that balloon

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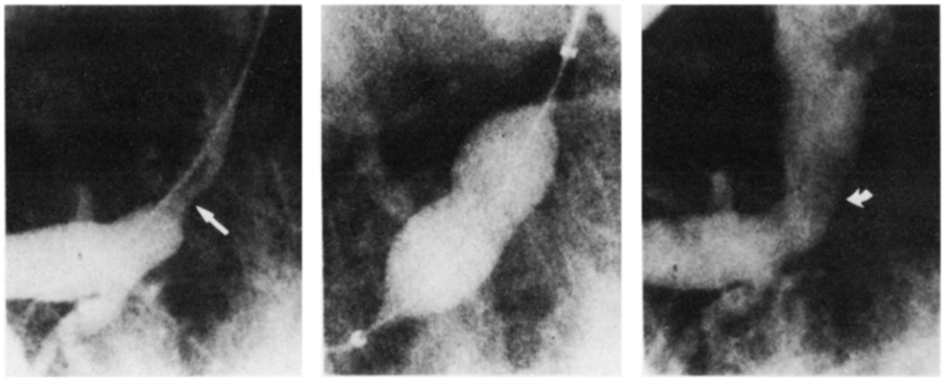

Figure 8. Successful balloon angioplasty of a superior vena cava-right pulmonary artery anastomosis from a percutaneous subclavian venous approach. **Left,** The straight arrow depicts the stenosis on the predilation angiogram. **Middle,** The inflated balloon angiogram. **Right,** The diameter has increased (curved arrow) after balloon angioplasty.

inflation in this region was the cause. Consequently, we currently take special care to advance the wire into the largest distal vessel and to avoid very distal balloon inflation. This may be part of the reason for the decrease in incidence of aneurysms after 1986. In addition, because of a high incidence of aneurysm formation and limited technical control, we now rarely perform intraoperative pulmonary artery balloon dilations.

The "natural" history of these aneurysms is unknown. In one instance, a large aneurysm was found at catheterization 2 months after angioplasty, and the patient died during surgical attempt to repair the aneurysm. Follow-up of six other patients suggests that the aneurysm does not change or perhaps decreases in size an average of 2 years after angioplasty.

Pulmonary edema. Three of the four patients who developed transient unilateral pulmonary edema were the subject of a previous report (11). Comparison of patients who developed pulmonary edema with those who did not suggested that an increase in vessel diameter >70%, an increase in distal pulmonary artery pressure >170% or a mean distal pressure >20 mm Hg increased the risk of pulmonary edema. The mechanism appears to be an acute increase in capillary perfusion pressure. Of the four patients, two had no symptoms and pulmonary edema was detected on postdilation angiograms. The other two patients had symptomatic hypoxia after dilation and within 72 h of conservative management had resolution of symptoms and of radiographic evidence of pulmonary edema.

Follow-up. The sustained increase in postdilation diameter at a mean follow-up interval of 10 months (range 1 to 54 months) suggests that the results of angioplasty generally persist long term. However, restenosis to predilation size did occur in 5 (16%) of the 32 restudied patients with initially successful dilation. No clear predictors of restenosis could be identified; predilation diameter, percent increase in diameter with angioplasty and age at dilation were not significantly different for arteries with and without restenosis. The mean follow-up time at which restenosis was detected was 4 months (in two patients as early as 2 months) suggesting that either dilation had caused only a transient stretch of the vessel or that the process of remodeling and fibrosis that results in restenosis is very rapid. In these cases, the use of an intravascular stent would appear to be warranted (21).

Conclusions. We consider balloon angioplasty to be an established, highly useful procedure in the management of branch pulmonary artery stenosis. It is successful in approximately 60% of patients. Current figures indicate a low but significant mortality rate (1%) and risk of aneurysm formation (3%). The prognosis after aneurysm formation remains undetermined, but preliminary follow-up suggests that none of the aneurysms have spontaneously ruptured and some may have become smaller. Patients undergoing balloon angioplasty early after pulmonary artery surgical repair constitute a particularly high risk group for vessel rupture. Restenosis after branch pulmonary artery dilation is infrequent, but does occur. Further improvements in the use of the procedure should probably involve the use of an expandable intravascular stent for patients with a failed dilation or evidence of restenosis.

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